2. Safety in Grounding

2.1 Basic Problem. In principle, a safe grounding design has two objectives:

(1) To provide means to carry electric currents into the earth under normal and fault conditions without exceeding any operating and equipment limits or adversely affecting continuity of service

(2) To assure that a person in the vicinity of grounded facilities is not exposed to the danger of critical electric shock

A practical approach to safe grounding thus concerns and strives for controlling the interaction of two grounding systems:

(1) The intentional ground, consisting of ground electrodes buried at some depth below the earth surface

(2) The accidental ground, temporarily established by a person exposed to a potential gradient in the vicinity of a grounded facility

People often assume that any object grounded, however crudely, can be safely touched. This misconception probably contributed to accidents in the past, as a low station ground resistance is not, in itself, a guarantee of safety. There is no simple relation between the resistance of the ground system as a whole and the maximum shock current to which a person might be exposed. Therefore, a station of relatively low ground resistance may be dangerous under some circumstances[7], while another station with very high resistance may be safe or can be made safe by careful design.

For instance, if a substation is supplied from an overhead line with no shield or neutral wire, a low grid resistance is important. A substantial part of the total ground fault current enters the earth causing an often steep rise of the local ground potential; Fig 2(a).

If a shield wire, gas-insulated bus, or underground cable feeder, etc, is used, a part of the fault current returns through this metallic path directly to the source. Since this metallic link provides a low impedance parallel path to the return circuit, the rise of local ground potential is ultimately of lesser magnitude; Fig 2(b).

In either case, the effect of that portion of fault current that enters the earth within the station area should be further analyzed. If the geometry, location of ground electrodes, local soil characteristics, and other factors contribute to an excessive potential gradient at the earth surface, the grounding system may be inadequate despite its capacity to carry the fault current in magnitudes and durations permitted by protective relays.

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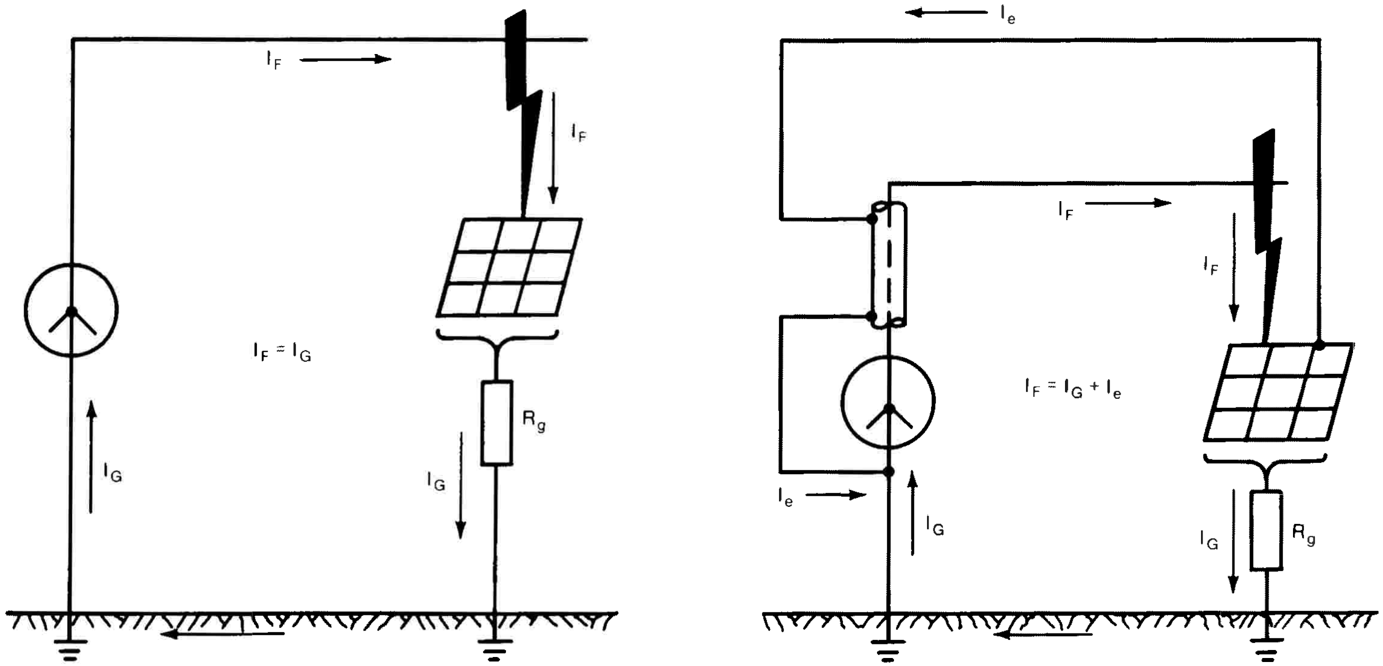
[7] One exception is the case in which the product of the maximum grid current I_G flowing in the earth via the grounding system resistance R_g results in a voltage low enough to be contacted safely.



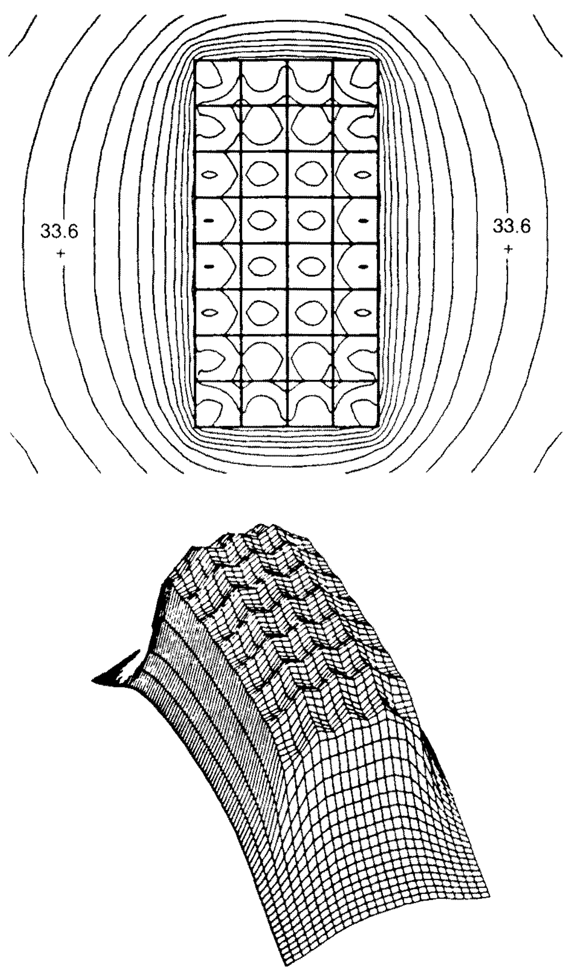
(a) (b)

Fig 2
Typical Faulted Substation With and Without Multiple Ground Return Paths

The following Sections 3-6 cover in detail those principal assumptions and criteria that enable us to evaluate all necessary factors in protecting the most precious element of the accidental circuit, human life.

2.2 Conditions of Danger. During typical ground fault conditions, the flow of current to earth will produce potential gradients within and around a substation. Figure 3 shows this effect for a station with a simple rectangular grounding grid in homogeneous soil.

Fig 3
Equipotential Contours of a Typical Grounding Grid With and Without Ground Rods



Unless proper precautions are taken in design, the maximum potential gradients along the earth surface may be of sufficient magnitude during ground fault conditions to endanger a person in the area. Moreover, dangerous potential differences may develop between structures or equipment frames that are grounded and the nearby earth.

The circumstances that make electric shock accidents possible are:

(1) Relatively high fault current to ground in relation to the area of ground system and its resistance to remote earth

(2) Soil resistivity and distribution of ground currents such that high potential gradients may occur at points at the earth surface

(3) Presence of an individual at such a point, time, and position that the body is bridging two points of high potential difference

(4) Absence of sufficient contact resistance or other series resistance to limit current through the body to a safe value under the above circumstances

(5) Duration of the fault and body contact, and hence, of the flow of current through a human body for a sufficient time to cause harm at the given current intensity

The relative infrequency of accidents of the type being studied, as compared to accidents of other kinds, is due largely to the low probability of coincidence of all the unfavorable conditions mentioned above.[8]

Nevertheless, some fatalities due to gradients have occurred in the past. Therefore, it is the responsibility of the engineer to lower this possibility.

[8] German Grounding Standard DIN 57141 (1977 edition) recognizes this low probability and allows reduction for grounding calculations of a given fault current magnitude by a certain factor. For instance, a 0.7 value is recommended for stations of 110 kV class and above.